(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
26 April 2001 (26.04.2001)

PCT

(10) International Publication Number
WO 01/28670 A1

(51) International Patent Classification⁷: B01F 5/02, 13/00, 3/08

(21) International Application Number: PCT/GB00/03989

(22) International Filing Date: 18 October 2000 (18.10.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

9924776.9	20 October 1999 (20.10.1999)	GB
0019756.6	11 August 2000 (11.08.2000)	GB
0019770.7	11 August 2000 (11.08.2000)	GB

(71) Applicant (*for all designated States except US*): **THE UNIVERSITY OF SHEFFIELD** [GB/GB]; Western Bank, Sheffield S10 2TN (GB).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): **ALLEN, Ray** [GB/GB]; Cherry Tree Cottage, Boars Hill, Oxford OX1 5DD (GB). **TIPPETTS, John** [GB/GB]; Barncroft, Vicarage Lane, Dore, Sheffield S17 3GX (GB). **TESAR, Vaclav** [CZ/GB]; 6 Severn Court, Severn Road, Sheffield S10 2UF (GB).

(74) Agents: **HUTCHINSON, Glenn**; Harrison Goddard Foote, Fountain Precinct, Leopold Street, Sheffield S1 2QD et al. (GB).

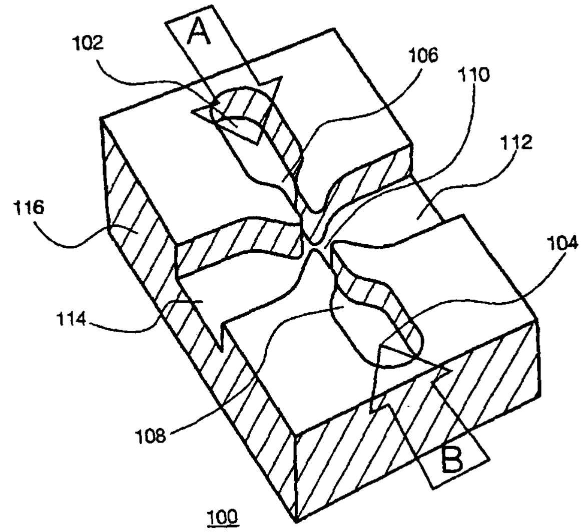
(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *With international search report.*
— *Before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments.*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: FLUIDIC MIXER



(57) Abstract: The present invention relates to a fluidic mixer that mixes two fluids without using mechanical stirrers. The two fluids are fed into an interaction cavity under predeterminable conditions that ensure the fluid flows oscillate and feed in an alternating manner two exit channels. The fluids in the exit channels form interleaved layers having widths related to the frequency of oscillation. The fluid have relatively Reynolds low numbers and preferably Reynolds numbers that are less than 100.

WO 01/28670 A1

FLUIDIC MIXER

The present invention relates to devices for mixing fluids and, in particular, to microfluidic mixers.

A well known problem in microchemistry is the efficient mixing of reactants. Such efficient mixing is crucial for almost all synthesis reactions. It is also essential in analytical chemistry where the results often strongly depend on the concentration of the reagents. It will be appreciated that classical mechanical stirrers do not provide a practical solution to the requirement for efficient and thorough mixing when the scale of the device of the mixing devices and the microreactors involved are of the order of several microns in size. A proposed solution which overcomes the difficulties associated with mechanical stirrers (which have a limited operating life and suffer from mechanical fatigue) are so called "static mixers". These static mixers generate small-sized volumes of fluid and bring them into mutual contact. A mixed formation is achieved by relying upon diffusive transport between the volumes. The fluids to be mixed are brought into contact in a longitudinal flow within a channel having a length determined by the rate of diffusion of the fluids to be mixed. To use effectively available space, channel lengths should be small which requires small sizes of volumes generated in the mixer.

Conventionally, high diffusion rates may be achieved in a turbulent flow regime in which the fluids to be mixed have associated Reynolds numbers that are relatively large so that turbulent mixing can occur.

However, such a turbulent flow regime is generally not available in microdevices with fluid flows having relatively low Reynolds numbers.

It is an object of the present invention to at least mitigate some of the problems of the prior art.

Accordingly, a first aspect of the present invention provides a fluidic mixer comprising a first nozzle and a second nozzle to feed a cavity having at least two exit channels; the first and second nozzles being arranged to produce mutually opposing first and second fluid flows that form in at least one exit channel interleaved layers of the first fluid and the second fluid.

Advantageously, embodiments of the present invention allow static fluidic mixers to be realised. In particular, embodiments can be realised to mix fluid flows at relatively low Reynolds numbers.

A second aspect of the present invention provides a mixer comprising a first nozzle and a second nozzle that feed a cavity having at least two exit channels; the first and second nozzles being arranged to produce mutually opposing flows of a first fluid and a second fluid that are arranged to oscillate to feed in an alternating manner the two exit channels.

Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings in which:

figure 1 illustrates a perspective view of the structure of a static mixer according to an embodiment;

figure 2a shows the perspective view of the static mixer illustrated in figure 1 together with an indication of the preferred relative dimensions of the features of that static mixer;

figure 2b shows in greater detail the structure of a nozzle of the embodiment of figure 2b;

figure 3 illustrates schematically the operation of a fluidic mixer;

figure 4 illustrates schematically a fluid feedback loop which was observed during the operation of a practical embodiment of the present invention;

figure 5 shows an approximate mathematical model for embodiments of a fluidic mixer;

figure 6 shows an embodiment of a two stage mixer in which two primary mixers feed a secondary mixer; and

figures 7a and 7b show two extreme positions of oscillating fluid flows.

Referring to figure 1 there is shown a microfluidic mixer 100 comprising a first inlet 102 for a first fluid and a second inlet 104 for a second fluid. The first inlet 102 has a first nozzle 106. The second inlet 104 has a corresponding second nozzle 108. Both the first nozzle 106 and the second nozzle 108 are directed towards an interaction cavity 110, that is, the nozzles are arranged to produce mutually opposing fluid flows, or at least fluid flows having mutually opposing components. The mixer 100 also comprises first 112 and second 114 exit channels. The axes of the first 112 and the second 114 exit channels are perpendicular to the axes of the first 106 and second 108 nozzles. It can be appreciated from figure 1 that the microfluidic mixer has been etched from a body 116. In some embodiments, the inlet was 2.94

times the nozzle width, b. However, it has been found that the behaviour of the nozzles is relatively insensitive to changes in inlet width providing there is a contraction of the cross-sectional area of the inlet as compared to the cross-sectional area of the nozzle which is of the order of a factor of two.

Referring to figure 2a there is shown the embodiment of a microfluidic mixer 100 as shown in figure 1 together with relative dimensions of the features of the microfluidic mixer. It can be seen that the inlets 102 and 104 have parallel walls 202 to 208 which are connected at the ends most remote from the respective nozzles 106 and 108 by semicircular surfaces 210 and 212. The parallel walls 202 to 208 are coupled with respective constriction portions 214 to 220 which narrow the inlets 102 and 104 to form respective nozzle channels 222 and 224 of the first 106 and second 108 nozzles.

Preferably, the constriction portions are formed as inflexions between first 226 and second 228 radii. The inflexion portions reduce the width of the inlets to the width of the channel of the nozzles. The constriction portions comprise, in an embodiment, respective linear portions between two different radii. The inflexions that form the constriction portions are defined by a convex (or inwardly turning) radius and a concave (or outwardly turning) radius preferably with a tangential linear portion therebetween. An inwardly turning radius is a radius which turns towards a respective nozzle axis and an outwardly turning radius is a radius which turns away from a respective nozzle axis.

Each nozzle has a nozzle exit formed by respective nozzle lips 230 and 232. The nozzle exits (and nozzle lips 230 and 232) are separated by a pre-determined distance, s. It can be appreciated that the nozzle lips protrude into the volume defined by the side walls 234 to 240 of the exit channels 112 and 114.

The nozzle lips comprise respective linear portions between two radii of pre-determinable values. The nozzles have respective axes (only the axis 242 of the first nozzle 106 is shown in figure 2). Preferably, the axes of the first 106 and second 104 nozzles are colinear. It can be appreciated from figures 2a and 2b that the linear portions of the constriction and the nozzle lips are substantially parallel and are inclined at a pre-determined angle relative to a respective nozzle axis. A preferred embodiment preferably has angles of inclination of 45°. However, it will be appreciated that other angles may be used which provide a sufficient contraction down to a preferred nozzle width. For example, the angles may take a value in the range of 20° to 60°.

In a preferred embodiment the nozzle width is b. The dimensions of the remaining features of the microfluidic mixer are defined relative to the nozzle width b. Preferably, b has submillimetre dimensions. However, the value of b will in practice be determined by the operating conditions for the mixer. Embodiments can be realised in which the value of b has a lower limit of 0.005 mm. Embodiment can be realised in which the value of b has an upper limit of 10 mm.

The inwardly turning radii of the constriction portions have radii r_1 = 2.9b. Preferably, the outwardly turning radii have radii of r_2 = 2.3b. The inflexions which form the lips of the nozzle have an inwardly turning radius of r_3 = 3.5b and an outwardly turning radius of r_4 = 0.3b. The linear portions of the nozzle lips have a length of l_1 = 1.04b. The separation, s, between the nozzle exits, that is, the inner most parts of the nozzle lips, is s=3b. The widths of the first 112 and second 114 exit channels are m=6.7b. The lengths of the channels of the nozzles 106 and 108 are l_2 = 1.4b. The widths of the first 102 and second 104 inlets are l_3=2.94b. Preferably, the aspect ratio of the device, that is, the aspect ratio of the nozzle channels as defined by $\lambda=\frac{h}{b}$ where h is the depth of the etched features of the micro fluidic mixer. Preferably h = 0.44b.

Although the above relative dimensions may be preferred, it will be appreciated that embodiments can be realised which deviate from the above preferred dimensions. There are, for some embodiments, preferred ranges of relative dimensions. Table 1 below illustrates preferred ranges of the dimensions which may be realised jointly or severally in any combination to achieve oscillation or mixing within embodiments of a microfluidic mixer.

Parameter name	**Parameter symbol**	**lower multiplier**	**upper multiplier**
Inlet channel width	l_3	2	10

First inflexion linear portion	l_1	1	5
second inflexion linear portion	l_2	1	5
First inflexion linear portion inclination angle	α_1	20	60
second inflexion linear portion inclination angle	α_2	20	60

Table 1

A practical, but relatively large scale, embodiment of the present invention was realised. The embodiment was operated using water. The fluid flow from the first nozzle comprised clear water. The fluid flow from the second nozzle comprised coloured water. The value of b for the practical embodiment was b=3.4mm. Table 2 shows various operating parameters associated with the practical embodiment. Indeed, table 2 illustrates two sets of operating conditions. The operating conditions are labelled G

and H.

Parameter	G	H
Re	410	415
u	1.1	1.81
Sh	0.041	0.022
Sk	16.8	9.1

Table 2

where the Reynolds number, $Re=\frac{bw}{\upsilon}$

Strouhal number $Sh=\frac{fb}{w}$, and

Stokes number $Sk = Re.\ Sh=\frac{fb^2}{\upsilon}$

where b = the nozzle width,

w is the fluid nozzle exit velocity;

f is the frequency of oscillation.

Referring to figure 3 there is shown a schematic illustration of a static mixer 300 which comprises first 302 and second 304 inlets that carry respective fluids 306 and 308. The fluids leave the inlets via nozzle exits 310 and 312. It can be seen that the first fluid 306 produces a flow which oscillates between two positions 314 and 316. The second fluid also produces a flow which oscillates between two positions. However, only one position 318 of the second flow is shown. A first exit channel carries the mixed first 306 and second 308 fluids. The nozzle exit velocities are both assumed to be w. It can be seen that the first 306 and second

308 fluids are initially carried in interleaved layers of thickness δ and at a velocity of w_p. The interleaved layers 322 result from the oscillation of the first 306 and second 308 fluids emanating from their respective nozzles. It will be appreciated that figure 3 is highly schematic. In practice the interleaved fluid layers are not linear, they assume a complex curved shape.

Referring to figure 4 there is shown a still photograph 400 taken from a video recording of the above practical realisation of a static mixer. The still clearly shows first 102 and second 104 inlets which feed the first 106 and second 108 nozzles. The fluid flow 402 emanating from the first nozzle 106 can be seen to form a feedback loop which influences the flow of the first nozzle. It has been observed that the fluid flow 402 is deflected to reach a substantially fully deflected position as shown in figure 4. It is thought that the fluid flow 402 when it finally arrives at the fully deflected position as shown in figure 4, cannot remain deflected and switches to the other exit channel. The fluid flow 402 is forced to straighten and after doing so performs a further traversal motion which results in the fluid flow being deflected into the other exit channel. It is thought that the overswing to the other exit channel is caused by fluid inertia. It is also thought that the feedback action of the leading front of the feedback loop may cause the fluid flow 402 to be deflected when that front acts on the fluid flow 402 as it emanates from the nozzle 106. An embodiment provides for the feedback loop of given nozzle to influence the

flow of fluid from that nozzle substantially at the exit of that nozzle. The feedback loops alternate, that is, oscillate about the respective axes of the nozzles.

Referring to figure 5 there is shown, without wishing to be bound by any theory, a current mathematical model of the oscillation of embodiments of the fluidic mixers. The model is used to estimate the length the feedback loop of a fluid flow, such a fluid flow 402 of figure 4. It can be seen that the expression for the feedback loop path length has been expressed in terms of the width of the interaction cavity, s, and the width of the exit channels, m. It can be seen that the approximate path length is given

$$\text{path length} = 2s + \left(\frac{m-s}{2}\right) = m+s = m\,(1+\sigma) \quad \text{where } \sigma = \frac{s}{m}$$

It will be appreciated that the simplified expression for the feedback loop path length does not consider transverse motion or transverse components of the feedback loop path. It can also be appreciated that the assumption is made that the fluid flow 402 reaches the opposing wall of the exit channel which, as can be observed from figure 4, it does not. Therefore, the simplified mathematical model shown in figure 5 has been adjusted to incorporate a dimensionless parameter, μ, which can be varied to allow the predicted oscillation frequency to match the experimentally determined oscillation frequency. Therefore, the corrected fluid flow path length is $m(\mu+\sigma)$ where μ is of the order of 1 and involves corrections for effects including the fluid velocity not being constant for the whole of the feedback loop path and the period not being equal to twice the

fluid flow traversal time.

It can be appreciated for the simplified mathematical model shown in figure 5 that the oscillation period is equal to twice the fluid flow traversal time. Therefore $\Delta t_p = \frac{2b}{\beta w}(1+\sigma)$ which equates to (two path lengths nozzle exit velocity), the frequency, f, is given by $f = \frac{1}{\Delta t_p} = \frac{\beta w}{2b(1+\sigma)}$ and the Strouhal number $Sh = \frac{fb}{w} = \frac{\beta}{2(1+\sigma)}$. The corrected expressions taking into account the value of μ are:

oscillation period $\Delta t_p = \frac{2b}{\beta w}(\mu+\sigma)$

frequency $f = \frac{1}{\Delta t_p} = \frac{\beta w}{2b(\mu+\sigma)}$; and

Strouhal number $= \frac{fb}{w} = \frac{\beta}{2(\mu+\sigma)}$

Table 3 below shows the experimental data derived from the above practical embodiment for the operating conditions shown in column G of table 2 above.

Experimental Data	
Parameter	**Value**
w	0.118 m/s
f	1.618 Hz
Sh	0.0466
Sk	17

Table 3

The frequency of oscillation of 1.618 Hz compares favourably with the theoretically predicted frequency of 1.783 Hz. It can be seen that there is an error of about 10% between the measured frequency and the predicted frequency. The predicted frequency may be made to match the experimental frequency if the corrected expressions are used with a value of $\mu = 1.1489$.

It will be appreciated that the frequency of oscillation varies according to required mixer operational parameters. Embodiments can be realised in which the predetermined frequency of oscillation has a value in the range of 0.2 Hz to 100 kHz.

Also the Strouhal number can also be made to vary. Embodiments are envisaged in which the Strouhal number takes a value in the range $0.01 \leq Sh \leq 0.4$. Preferably, an embodiment is envisaged in which $Sh = 0.04$.

The process of producing interleaved layers of fluid 322 as shown in figure 3 can, without wishing to be bound by any particular theory, be modelled as follows. The time taken to form one layer is approximately equal to one half of the oscillation period Δt_p. During that time the flow in the exit channels travels a distance given by

$w_p \Delta t_p/2$.

This gives rise to a layer thickness

$$\delta = w_p \frac{b}{\beta w} (\mu+\sigma) .$$

Due to the continuity condition, $w_p=bw/m$, the thickness of the generated layer, relative to the nozzle

exit width, is $\frac{\delta}{b} = \mu+\sigma$. Inserting the above values leads to a theoretical prediction of $\frac{\delta}{b}$ = 1.6, which compares very favourably with the actual value determined from experiment G of $\frac{\delta}{b}$=1.53.

It will be appreciated that the parameters governing the interleaved layer thickness δ are balanced to achieve within a required length of the exit channel, mixing by diffusive transport of the first 306 and second 308 fluids.

As mentioned above, it can be very desirable in certain situations to ensure that efficient mixing of reactants is achieved for synthesis reactions. Furthermore, in analytical chemistry, when the results often strongly depend on the concentration of the reagents, thorough mixing is even more desirable. Therefore, an embodiment of the invention provides a plurality of static mixers such as shown in figure 6. Figure 6 shows a two stage mixer 600 which mixers first 602 and second 604 fluids. The two stage mixer 600 comprises two primary mixers 606 that are arranged to feed a secondary mixer 608. At least one or both of the primary and secondary mixers may be realised using any or a combination of the above embodiments. It can be seen that the exit channels 610, 612 and 614 of the primary mixers 606 are arranged to feed or coincide with the inlets for the nozzles 616 and 618 of the secondary mixer 608. The mixed fluid contained in the exit channels 620 and 622 of the secondary mixer 608 can then be output for further processing.

In a preferred embodiment, the two stage mixer 600 comprises a number of separate channels 624. The separate channels 624 are fed from the exit channels 602 and 622 of the secondary mixer 608.

Although the embodiment shown in figure 6 uses first and second fluid to feed both of the primary mixers, it will be appreciated that the present invention is not limited thereto. Embodiments can be realised in which the two primary mixers are used to different fluids. The mixed different fluids would then, in turn, be mixed within the secondary mixer.

Preferably, the above embodiments are operated at Reynolds numbers which are of the order of less than 450, and preferably of the order of 10 to 100.

In a preferred embodiment the plurality of channels 624 are arranged to feed respective microreactors for high throughout catalyst testing.

It will be appreciated that the above embodiments are substantially planar. A cover or top plates containing through holes is arranged to cover the etched features. The through holes are arranged to coincide with the inlet and outlets of the mixer.

A number of stills take from a video recording of the operation of the practical embodiment of the mixer are shown in figures 7a to 7b. In figure 7a, a first fluid 700 has been deflected to one side of the nozzle axes while the second fluid 702 has been deflected to the

other side of the nozzle axes. Accordingly, in the still of figure 7a, the first fluid feeds the flow 704 of the upper outlet channel and the second fluid feeds the flow 706 of the lower outlet channel. Referring to figure 7a, it can be appreciated that the position is the reverse of that shown in figure 7a. The first fluid 700 has been deflected downwards to feed the flow 706 carried by the lower outlet channel. The second fluid 702 has been deflected upwards to feed the flow 704 carried by the upper outlet channel.

It will be appreciated that embodiments of the present invention are arranged to mix substantially different fluids having differing viscosities, flow rates etc. Therefore, each nozzle would be arranged to accommodate a respective fluid. The embodiments described above are substantially symmetrical. However, embodiments can be realised that are asymmetrical, which may result from mixing different fluids. In such asymmetrical embodiments the nozzle widths would be calculated for a respective fluid. If the fluids were different, the respective nozzle widths would be different.

It has been observed that the aspect ratio of the nozzle influences the degree and/or frequency of oscillation. Preferably, the above embodiments are provided in which the aspect ratio is greater than one. However, the above embodiments, in some applications, may find an aspect ratio of one or less to be acceptable.

Although the above embodiments have been described with reference to a preferred value of $l_2 = 1.4b$, the

other side of the nozzle axes. Accordingly, in the still of figure 7a, the first fluid feeds the flow 704 of the upper outlet channel and the second fluid feeds the flow 706 of the lower outlet channel. Referring to figure 7a, it can be appreciated that the position is the reverse of that shown in figure 7a. The first fluid 700 has been deflected downwards to feed the flow 706 carried by the lower outlet channel. The second fluid 702 has been deflected upwards to feed the flow 704 carried by the upper outlet channel.

It will be appreciated that embodiments of the present invention are arranged to mix substantially different fluids having differing viscosities, flow rates etc. Therefore, each nozzle would be arranged to accommodate a respective fluid. The embodiments described above are substantially symmetrical. However, embodiments can be realised that are asymmetrical, which may result from mixing different fluids. In such asymmetrical embodiments the nozzle widths would be calculated for a respective fluid. If the fluids were different, the respective nozzle widths would be different.

It has been observed that the aspect ratio of the nozzle influences the degree and/or frequency of oscillation. Preferably, the above embodiments are provided in which the aspect ratio is greater than one. However, the above embodiments, in some applications, may find an aspect ratio of one or less to be acceptable.

Although the above embodiments have been described with reference to a preferred value of $l_2 = 1.4b$, the

present invention is not limited to that value. The above embodiments can be varied such that l_2 has a value given by $0.5b \leq l_2 \leq 10b$.

CLAIMS

1. A fluidic mixer comprising a first nozzle and a second nozzle to feed a cavity having at least two exit channels; the first and second nozzles being arranged to produce mutually opposing first and second fluid flows that form in at least one exit channel interleaved layers of the first fluid and the second fluid.

2. A mixer comprising a first nozzle and a second nozzle that feed a cavity having at least two exit channels; the first and second nozzles being arranged to produce mutually opposing flows of a first fluid and a second fluid that are arranged to oscillate to feed in an alternating manner the two exit channels.

3. A mixer as claimed in any preceding claim that is arranged to produce a first feedback loop fluid flow of at least the first fluid such that the first feedback loop fluid flow influences the flow of the first fluid from the first nozzle.

4. A mixer as claimed in claim 3 in which the influence of the first feedback loop fluid flow on the first fluid is exerted at the first nozzle exit.

5. A mixer as claimed in either of claims 3 and 4 in which the first feedback loop fluid flow causes the first fluid flow to form second feedback loop fluid flow.

6. A mixer as claimed in claim 5 in which the turning sense of the first feedback loop fluid flow is opposite to the turning sense of the second feedback loop fluid flow.

7. A mixer as claimed in either of claims 5 and 6 in which the first and second feedback loop fluid flows are disposed on opposite sides of colinear axes of the first and second nozzles.

8. A mixer as claimed in any preceding claim that is arranged to produce a feedback loop fluid flow of at least the second fluid such that the feedback loop fluid flow influences the flow of the second fluid from the first nozzle.

9. A mixer as claimed in any of claims 3 to 8, in which the influence exerted causes the first and second fluid flows to oscillate and feed in an alternating manner different ones of the two exit channels.

10. A fluidic mixer comprising a first inlet and a second inlet for feeding respective first and second nozzles, the nozzles having substantially colinear axes and being arranged to produce mutually opposing first and second fluid flows within a cavity, the cavity having two exit channels, the nozzles having profiled lips that protrude into a volume and define first and second exit channels.

11. A fluidic mixer as claimed in claim 10 in which the width of at least one of the first and second

nozzles is b.

12. A mixer as claimed in either of claims 10 and 11 in which at least one of the first and second has a predeterminable aspect ratio, λ.

13. A mixer as claimed in any of claims 10 to 12 in which the depth of the mixer has a predeterminable value, h.

14. A mixer as claimed in any preceding claim in which at least one of the first and second nozzles comprises a nozzle channel having a predeterminable length.

15. A mixer as claimed in claim 14 in which the channel length is given by $0.5b \leq l_2 \leq 10b$, and preferably $l_2 = 1.4b$, where b is the width of a respective nozzle.

16. A mixer as claimed in either of claims 14 and 15 in which the first nozzle comprises a first inlet of a predetermined width.

17. A mixer as claimed in claim 16 in which the predetermined width is given by $0.005\ mm \leq b \leq 10\ mm$.

18. A mixer as claimed in either of claims 16 or 17 in which the first inlet comprises a first profiled surface which narrows the first inlet from the predetermined width to the nozzle width.

19. A mixer as claimed in claim 18 in which the first

profiled surface comprises a first inflexion between a first radius and second radius to form a wall between a respective nozzle exit and a respective exit channel.

20. A mixer as claimed in claim 19 in which the first inflexion comprises a first inflexion linear portion that is substantially linear portion between the first and second radii.

21. A mixer as claimed in either of claims 19 and 20 in which the first radius has a predeterminable value given by r_1=2.9b, where b is the nozzle width at least one of the first and second nozzles.

22. A mixer as claimed in any of claims 19 to 21 in which the second radius has a predeterminable value given by r_2=2.3b, where b is the nozzle width a respective nozzle.

23. A mixer as claimed in any of claims 14 to 22 in which the at least one of the first and second nozzles has a second profiled surface.

24. A mixer as claimed in claim 23 in which the second profiled surface is a second inflexion between a third radius and fourth radius to form a wall between a respective nozzle exit and a respective exit channel.

25. A mixer as claimed in claim 15 in which the inflexion comprises a second inflexion linear portion that is substantially linear between the

third and fourth radii.

26. A mixer as claimed in either of claims 24 and 25 in which the third radius has a predeterminable value given by $r_3=3.5b$, where b is the nozzle width of at least one of the first and second nozzles.

27. A mixer as claimed in any of claims 24 to 26 in which the fourth radius has a predeterminable value given by $r_4=0.3b$, where b is the nozzle width a respective nozzle.

28. A mixer as claimed in any preceding claim in which the first inflexion linear portion is inclined at a predetermined angle relative to the axis of a respective nozzle.

29. A mixer as claimed in claim 28 in which the predetermined angle is between 20° and 60°.

30. A mixer as claimed in claim 29 in which the predetermined angle is 45°.

31. A mixer as claimed in any preceding claim in which the second inflexion linear portion is inclined at a predetermined angle relative to an axis of a respective nozzle.

32. A mixer as claimed in claim 31 in which the predetermined angle is between 20° to 60°.

33. A mixer as claimed in claim 32 in which the predetermined angle is 45°.

34. A mixer as claimed in any preceding claim in which the cavity provides a predetermined separation between the exits of the first and second nozzles.

35. A mixer as claimed in claim 34 in which the predetermined separation is determined by s=3b, where b is the width of a respective nozzle.

36. A mixer as claimed in any preceding claim in which the fluid flow rate of fluid in at least one of the two exits channels is selected according to a molecular diffusion path length of the first and second fluids.

37. A mixer as claimed in any preceding claim in which the first and second fluids are arranged to oscillate at a predetermined frequency.

38. A mixer as claimed in claim 37 in which the predetermined frequency has a value in the range of 0.2 Hz to 100 kHz.

39. A mixer as claimed in either of claims 37 and 38 in which the predetermined frequency is given by

$$\text{frequency } f=\frac{1}{\Delta t_p}=\frac{\beta w}{2b(\mu+\sigma)}.$$

40. A mixer as claimed in any preceding claim in which the Reynolds number of at least one of the first and second fluid flows in less than 450.

41. A mixer as claimed in claim 40 in which the Reynolds number of at least one of the first and second fluid flows is less than 100.

42. A mixer as claimed in claim 40 in which the Reynolds number of at least one of the first and second fluid flows in less than 10.

43. A mixer as claimed in any preceding claim in which at least one of the first and second fluid flows has a Strouhal number of $0.01 \leq Sh \leq 0.4$.

44. A mixer as claimed in claim 43 in which at least one of the first and second fluid flows has a Strouhal number of $Sh = 0.04$.

45. A fluidic mixer substantially as described herein with reference to and/or as illustrated in the accompanying drawings.

46. A mixer comprising a first mixer as claimed in any preceding claim arranged so that an exit channel of the first mixed is arranged to feed an inlet of a second mixer as claimed in any preceding claim.

47. A two-stage mixer comprising two primary mixers as claimed in any preceding claim arranged to feed respective inlets of a secondary mixer as claimed in any preceding claim.

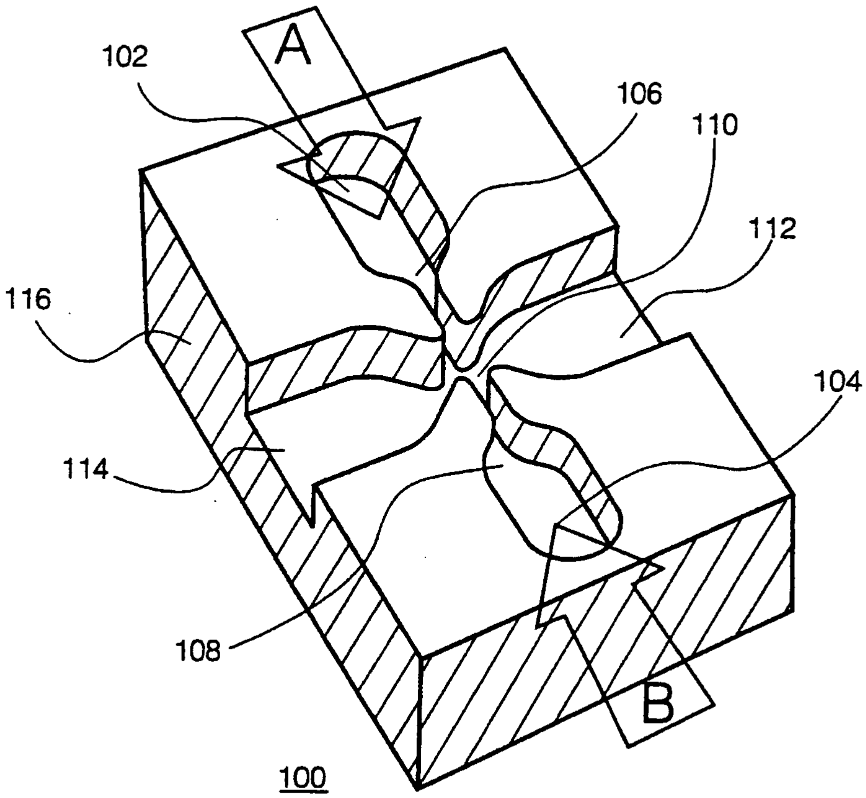


Fig. 1

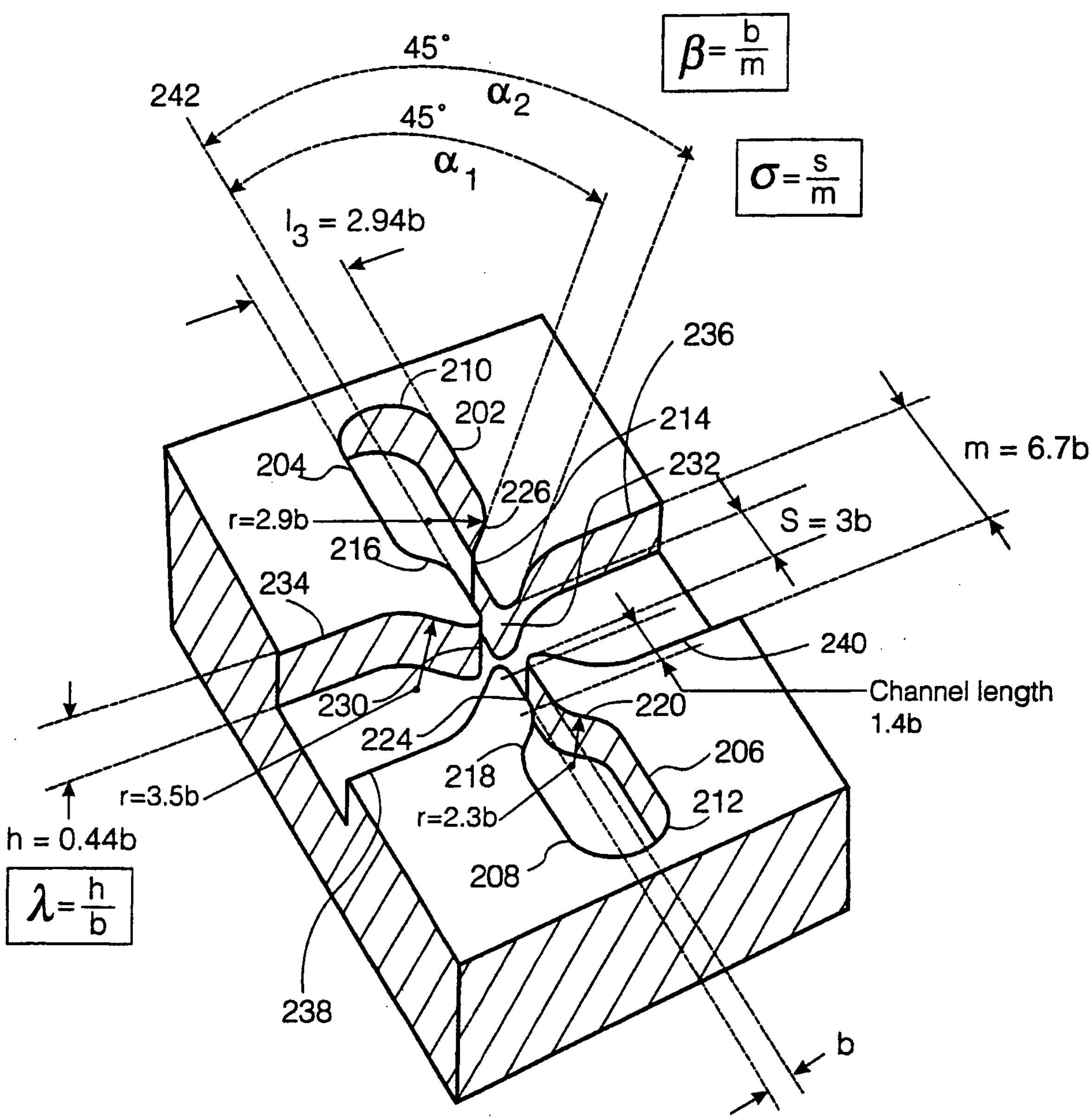

45°
α2
45°
α1
242
β = b/m
σ = s/m
l3 = 2.94b
236
210
202
214
m = 6.7b
204
232
226
r=2.9b
S = 3b
216
234
240
Channel length
1.4b
230
220
224
206
218
r=3.5b
r=2.3b
212
h = 0.44b
λ = h/b
208
238
b

Fig. 2a

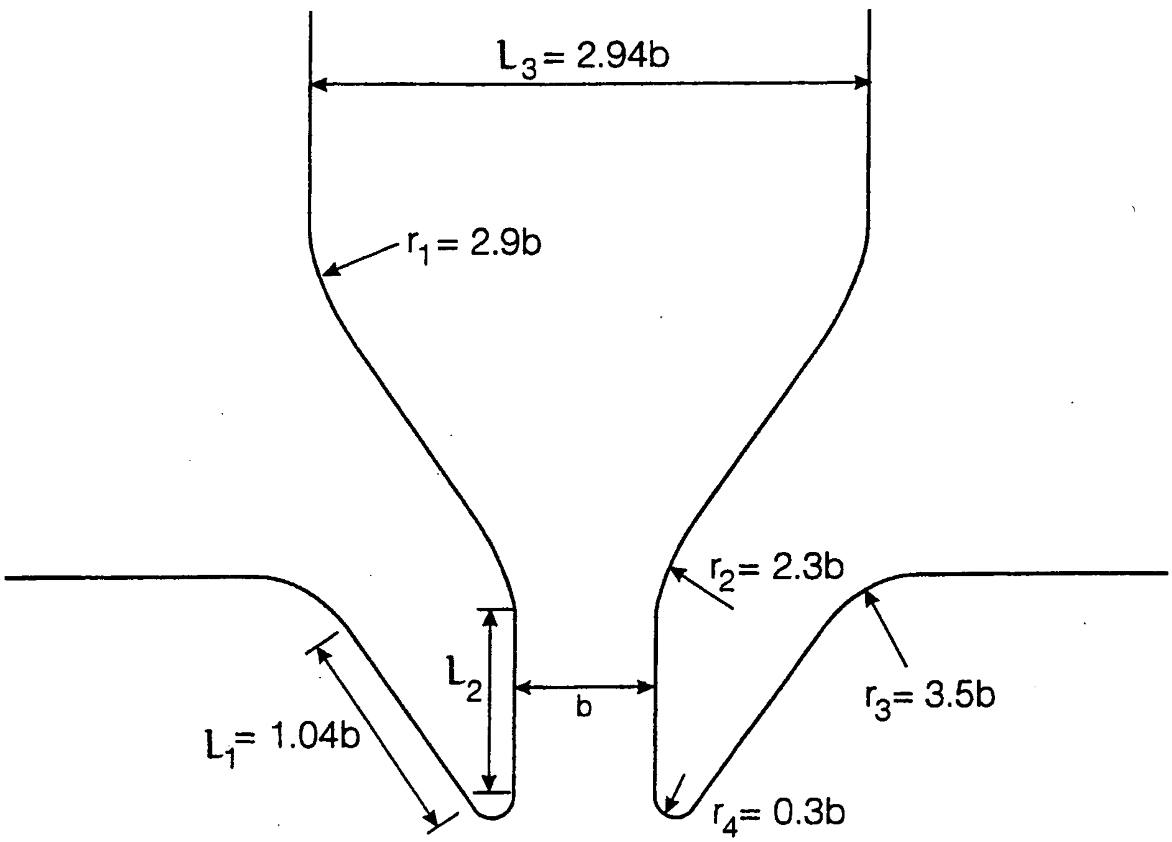


Fig. 2b

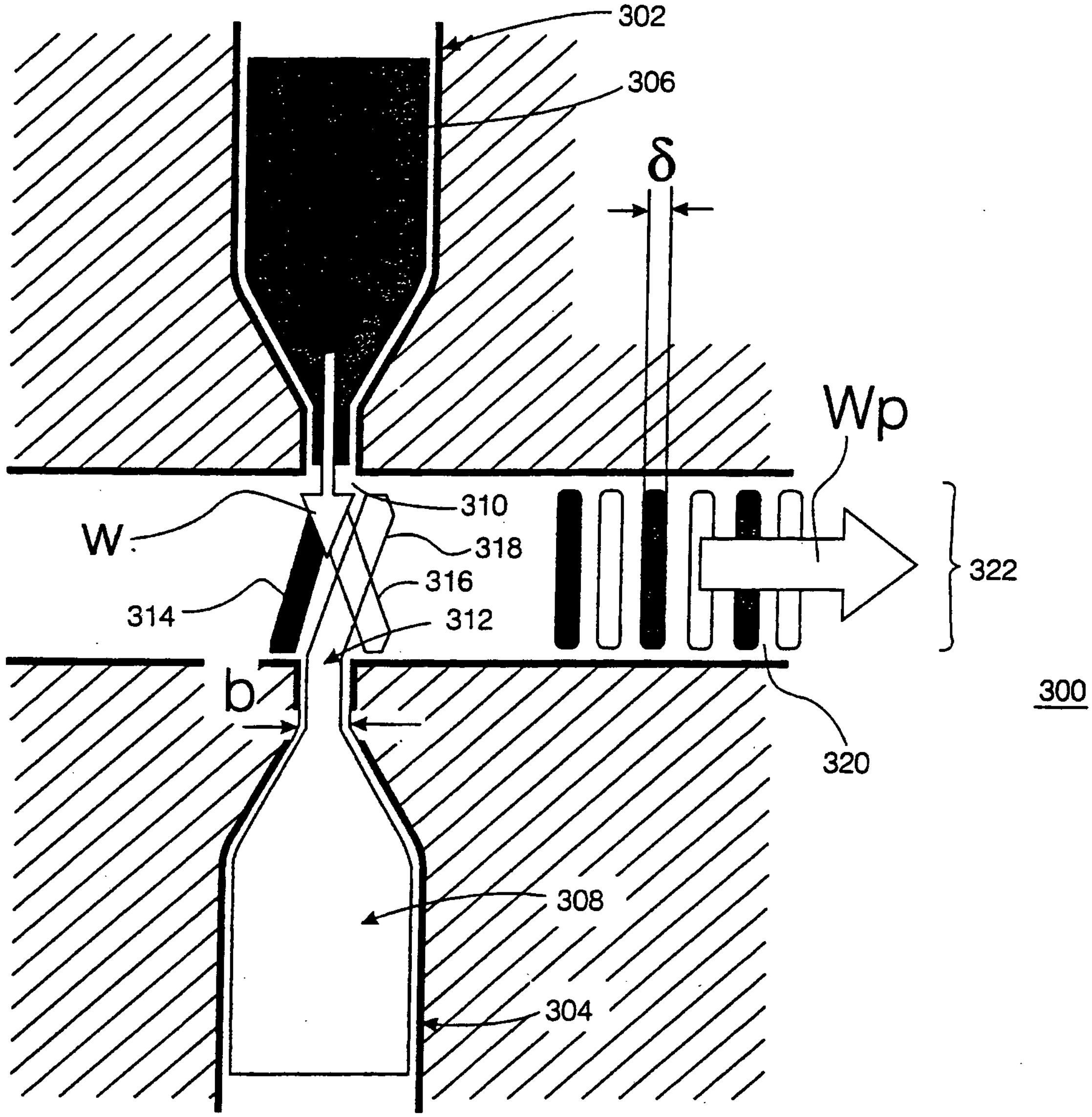


Fig. 3

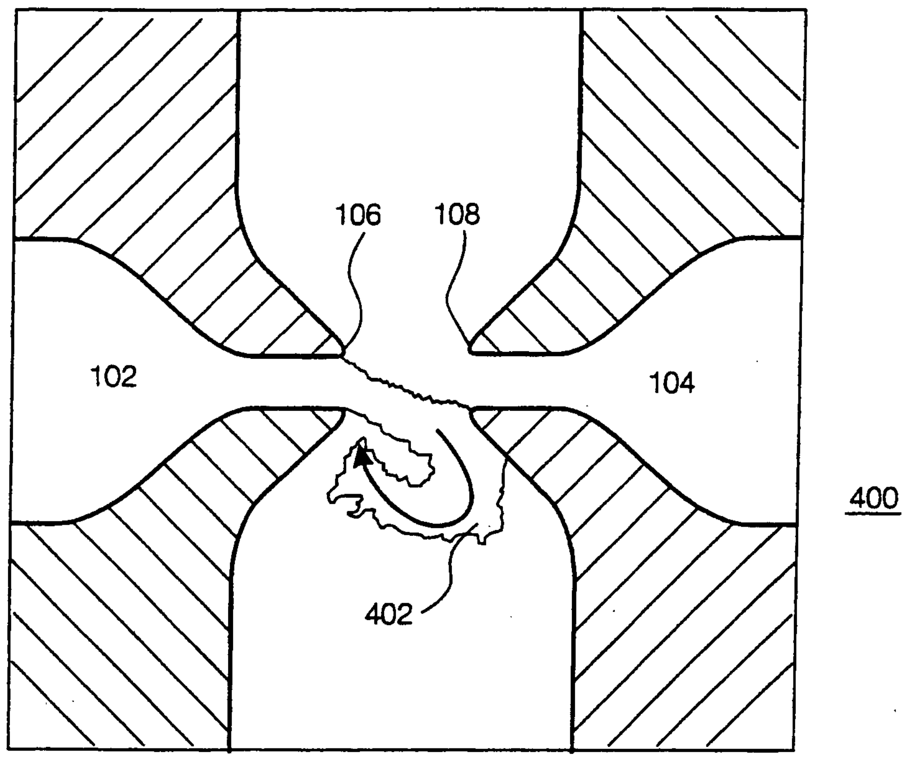


Fig. 4

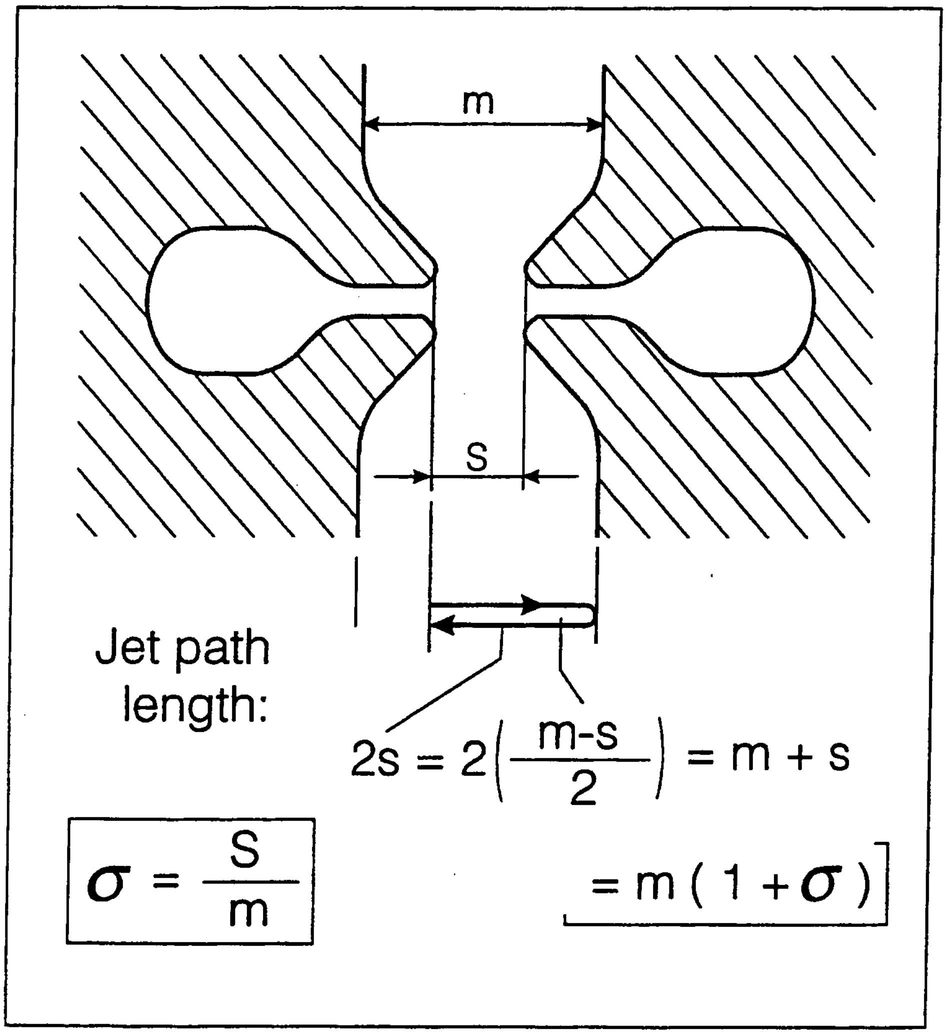

m
s
Jet path
length:
$2s = 2\left(\frac{m-s}{2}\right) = m + s$
$= m(1 + \sigma)$
$\sigma = \frac{S}{m}$

Fig. 5

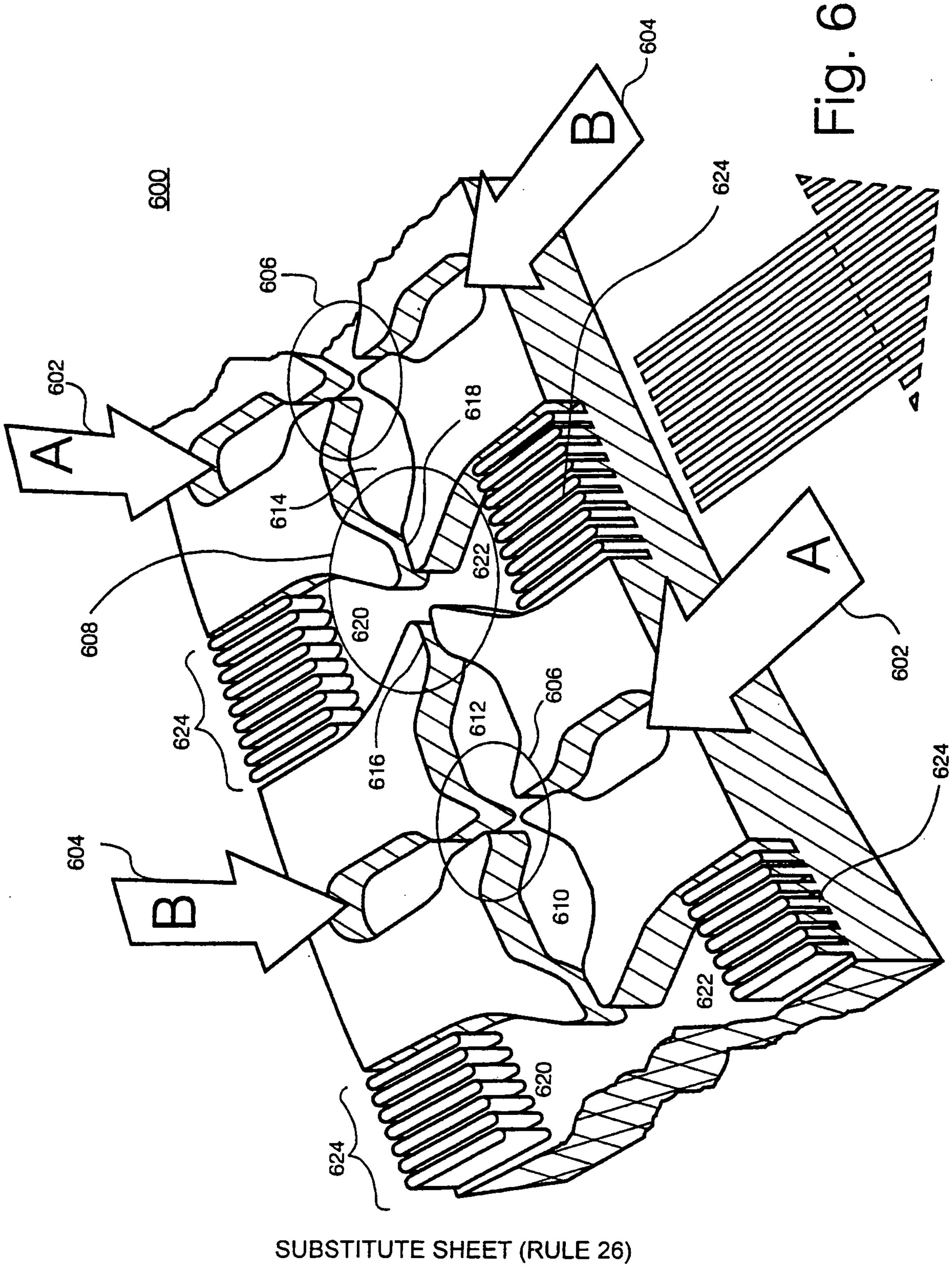


Fig. 6

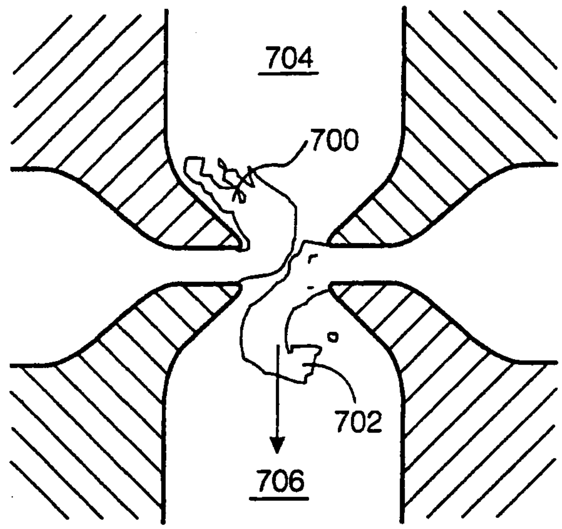


Fig. 7a

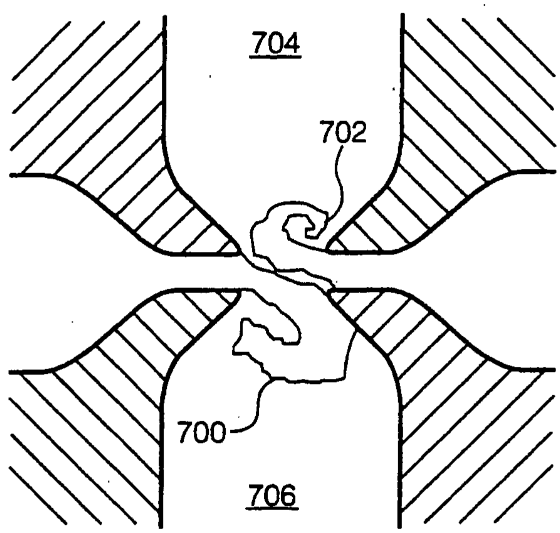


Fig. 7b

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/03989

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 B01F5/02 B01F13/00 B01F3/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 B01F B01J F15C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	BRANEBJERG J ET AL: "FAST MICING BY LAMINATION" PROCEEDINGS OF THE ANNUAL INTERNATIONAL WORKSHOP ON MICRO ELECTRO MECHANICAL SYSTEMS,US,NEW YORK, IEEE, vol. WORKSHOP 9, 11 February 1996 (1996-02-11), pages 441-446, XP000689310 ISBN: 0-7803-2986-4 the whole document	1-47
A	DE 195 36 856 A (DANFOSS AS) 10 April 1997 (1997-04-10) the whole document	1-47
A	DE 199 19 638 A (MEONIC SYS ENG GMBH) 16 September 1999 (1999-09-16) the whole document	1-47

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 February 2001	05/03/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Labeeuw, R

1

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/03989

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 3 446 228 A (STOUFFER RONALD D ET AL) 27 May 1969 (1969-05-27) the whole document	1-47
A	NL 7 012 762 A (N.V. BEKAERT S.A.) 1 March 1972 (1972-03-01) the whole document	1-47
A	US 3 601 137 A (BAUER PETER) 24 August 1971 (1971-08-24) the whole document	1-47

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 00/03989

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE 19536856 A	10-04-1997	AU 7125996 A	28-04-1997
		WO 9712665 A	10-04-1997
		EP 0853490 A	22-07-1998
		JP 11512645 T	02-11-1999
DE 19919638 A	16-09-1999	AU 5671400 A	17-11-2000
		WO 0067241 A	09-11-2000
US 3446228 A	27-05-1969	NONE	
NL 7012762 A	01-03-1972	NONE	
US 3601137 A	24-08-1971	NONE	